



ELSEVIER

International Journal of Industrial Ergonomics 26 (2000) 125–131

International Journal of

**Industrial  
Ergonomics**

www.elsevier.nl/locate/ergon

## Editorial

### Human factors in aviation maintenance: how we got to where we are

#### Abstract

Human factors in aviation has traditionally concentrated on aircrew and air traffic control errors, but the increasing number of maintenance and inspection errors has seen the rise of human factors research and interventions in this area. This paper provides the rationale for such work and gives an overview of the domain, both of which may not be familiar to human factors and ergonomics practitioners. The papers in this special issue are placed into the context of the human factors tools they employ and the interventions they develop, showing that most are extensions of existing techniques applied to a domain with a distinctive culture and unique challenges. Finally, recent advances, beyond the research represented by fully developed papers, are outlined to enable the reader to locate current and future work in this field. © 2000 Elsevier Science B.V. All rights reserved.

#### 1. Why aviation maintenance human factors?

A sound aircraft inspection and maintenance system is important in order to provide the public with a continuing safe, reliable air transportation system (FAA, 1991). This system is a complex one with many interrelated human and machine components. Its linchpin, however, is the human. While most often research and development related to human factors in aviation has focused on the pilot and the cockpit working environment, there have been maintenance initiatives. Under the auspices of the National Plan for Aviation Human Factors, the FAA has recognized the importance of the role of the human in aircraft safety, focusing research on

the aircraft inspector and the aircraft maintenance technician (AMT) (FAA, 1991, 1993). The classic term, “pilot error” or “human error”, is attributed to accidents or incidents over 75% of the time; however, a recent study in the United States found that 18% of all accidents indicate maintenance factors as a contributing agent (Phillips, 1994). Table 1 lists recent incidents/accidents where the probable cause was maintenance-related.

In each of these cases, a change in some aspect of the organization related to human performance – improved inter-airline communications; adherence to maintenance procedures and/or manufacturer specifications; and an increased diligence in maintenance, repair, and final inspection procedures – would probably have prevented the accident. In the example of the Continental Express accident in 1991, failure to complete a repair and notify the subsequent work shift led to a revenue flight before the aircraft was ready. Subsequent structural failure resulted in an accident causing multiple fatalities.

As a result of such incidents, the public has become more aware of the importance of aircraft maintenance as a safety issue, and both the civil aviation industry and its regulatory bodies have responded with programs to increase safety. Such programs have included hardware-based initiatives, such as the FAA’s Aging Aircraft Program, and human factors initiatives by the FAA and many international bodies, for example by Transport Canada and the European JAA.

This special issue primarily examines the fruits of one response, the FAA’s initiative on Human Factors in Aviation Maintenance and Inspection under the auspices of the FAA’s Office of Aviation Medicine. However, other initiatives from manufacturers and airlines are also included. We start with an overview of the aviation maintenance domain, which may be unfamiliar to the general human

Table 1  
Maintenance related incidents and accidents

Airline	Location	Year	Incident/issue
Aloha Airlines 737	Hawaii	1988	Inspection failure led to fuselage failure
BM AirTours 737	Manchester	1989	Wrong bolts led to windshield blowout
United Airlines DC10	Iowa	1989	Engine inspection failure led to loss of systems
Continental Express	Texas	1991	Tail failure as task not completed before flight
Northwest Airlines	Tokyo	1994	Incomplete assembly led to engine separation
ValueJet	Florida	1996	Fire in hold due to incendiary cargo

factors and ergonomics community. Most perhaps have not spent a long night shift working with skilled inspectors examining the structural condition of an airliner's baggage hold or worked on a frozen ramp dispatching flights safely and on time.

## 2. The domain of aviation maintenance and inspection

The rapid growth of the airline industry has emphasized the importance of effective and efficient maintenance. Fig. 1 shows the percentage of growth in the United States airline industry over a 10-year period ending in 1993 (Air Transport Association, 1994).

This growth is representative of airlines worldwide. Revenue, passenger miles flown, and the number of aircraft have all exceed the overall growth of the AMT workforce. Furthermore, new skills and knowledge are required to maintain the modern technologically advanced aircraft. Finally, there has been a continuing decline in both the number of people applying to training programs for AMTs and the percentage of program graduates who stay in aviation. An obvious conclusion is that AMTs must raise efficiency to match the increasing workload. Thus, the aircraft maintenance industry must work to ensure that technicians become more capable, and processes and procedures more efficient and effective. Since it is difficult to eliminate errors completely, continuing emphasis must be placed on developing interventions to make the inspection/maintenance procedures more reliable and/or more error tolerant (e.g., Drury et

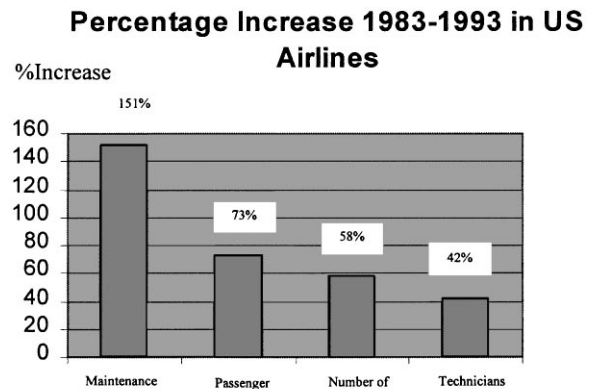


Fig. 1. Percentage increase 1983–1993 in US airlines.

al., 1990; Shepherd and Wraus 1997; Shepherd et al., 1995).

In addition, the aircraft inspection/maintenance system is affected by a variety of geographically dispersed entities ranging from large international carriers, repair, and maintenance facilities through regional and commuter airlines to the fixed-based operators associated with general aviation (Drury et al., 1990; FAA, 1991). In the United States maintenance and inspection are regulated by the FAA. However, while adherence to maintenance and inspection procedures and protocols is closely monitored, determining the efficacy of these procedures is much more difficult. These procedures derive initially from a design process (MSG-3) that specifies the potential failure of each aircraft structure and system, and the way to ensure that these failures do not affect public safety. Thus, for cracks in aircraft structures, inspection intervals are defined based on the mechanics of crack growth and the reliability of the inspection procedures. Just as

effective maintenance and inspection are seen as a necessary prerequisite to maintenance safety, inspector reliability is fundamental to effective maintenance and inspection. It is critical that these operations be performed effectively, efficiently, and consistently.

Fig. 2 provides a flowchart of the maintenance and inspection process. Aircraft for commercial use have their maintenance scheduled initially by

a team that includes the FAA, aircraft manufacturers, and start-up operators. These schedules are then taken by the carrier and modified so that they suit individual carrier requirements and meet legal approval. Thus, within the carrier's schedule there will be checks at various intervals, often designated as flight line checks, overnight checks, and A, B, C, and D (the heaviest) checks. The objective of these is to conduct both routine and non-routine main-

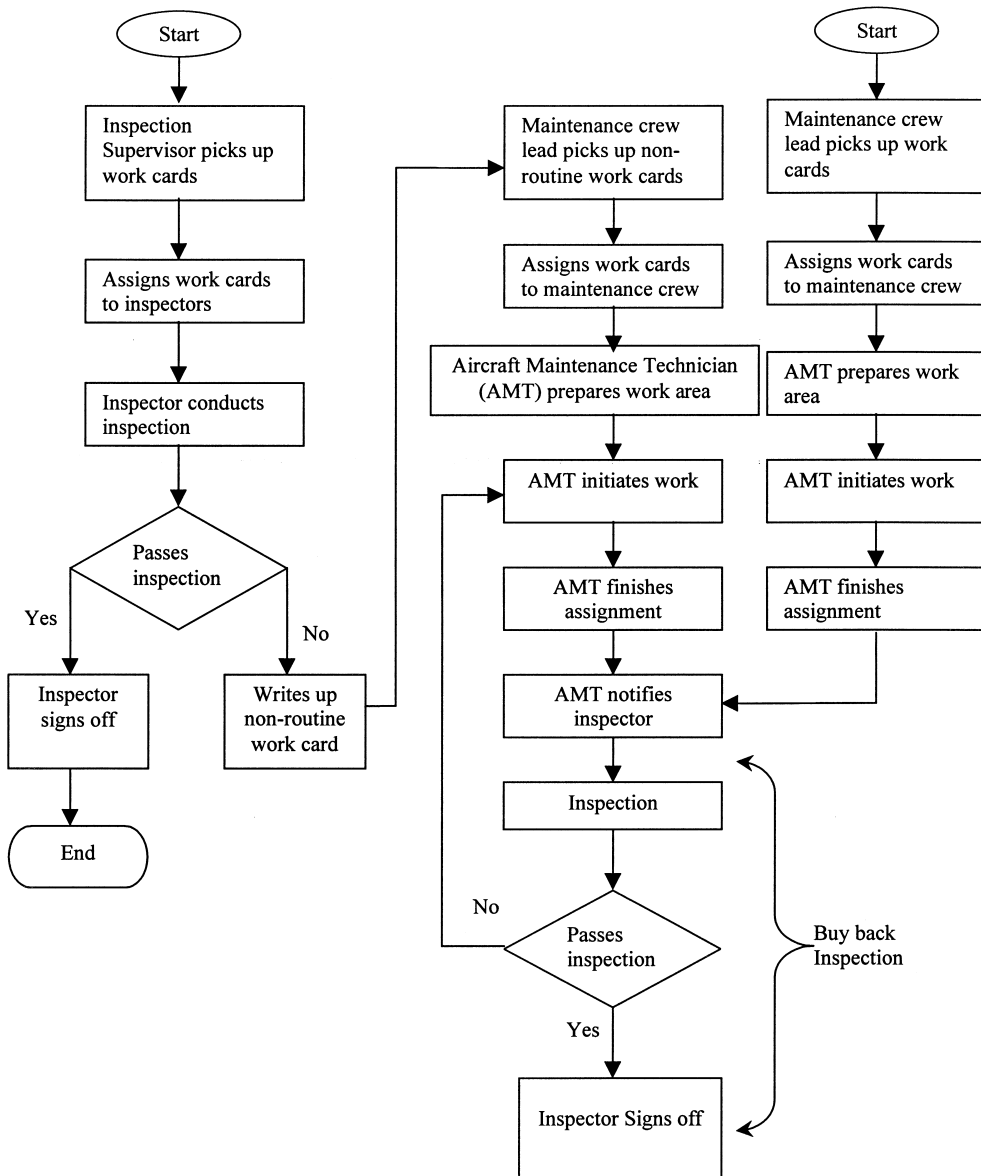


Fig. 2. Maintenance and inspection flow chart.

tenance of the aircraft. This maintenance includes scheduling the repair of known problems; replacing items after a certain air time, number of cycles, or calendar time; repairing defects discovered previously from reports logged by pilots and crews or items deferred from previous maintenance; and performing scheduled repairs. Inspections often lead to repairs/maintenance if a defect is discovered by the inspection system. In the context of an aging fleet, inspection takes on a more vital role where scheduled repairs account for only 30% of all maintenance compared to 60–80% for a younger one, a direct reflection of the increase in the number of age-related defects (FAA, 1991).

Once maintenance and inspection are scheduled for an aircraft, they are translated into a set of job cards or work cards giving the instructions for inspection and maintenance as the aircraft arrives at the maintenance site. Initially, the aircraft is cleaned and access hatches opened so that inspectors can view the different areas. This activity is followed by a heavy inspection check, most of which is visual. Since such a large part of the maintenance workload is dependent on the discovery of defects during inspection, it is imperative that the incoming inspection be completed as soon as possible after the aircraft arrives at the inspection maintenance site. Furthermore, there is pressure on the inspector to discover critical defects that necessitate long follow-up maintenance times early in the inspection process. Thus, there is a heavy inspection workload at the commencement of each check. It is only after the discovery of defects that the planning group can estimate expected maintenance workload, order replacement parts, and schedule maintenance items. Frequently, maintenance facilities resort to overtime, resulting in an increase in the total number of inspection hours, a practice often leading to prolonged work hours. Also, much of the inspection, including routine inspection on the flight line, is carried out during the night shift between the last flight of one day and the first flight of the next. During inspection, each defect is written up as a non-routine repair (NRR) record. This is translated into a set of work cards to rectify the defect, a task accomplished by the maintenance crew. Once corrected, the defect might generate additional inspection to

ensure that the work meets necessary standards. These subsequent inspections are typically referred to as “buyback” inspections.

Task analysis of maintenance activities has revealed it to be a complex sociotechnical system, requiring above average coordination, communication, and cooperation between inspectors, maintenance personnel, supervisors, and various other sub-systems such as planning, stores, clean-up crews, and shops to be effective and efficient (Drury et al., 1990; Taylor, 1990; Gramopadhye and Kelkar, 1999). A large portion of the work done by inspectors and maintenance technicians is accomplished through teamwork. The challenge is to work autonomously but still be a part of the team. In a typical maintenance environment, the inspector first looks for defects and reports them. The maintenance personnel then repair the reported defects and work with the original or buy-back inspector to ensure that the job meets predefined standards. During the entire maintenance and inspection process, the inspectors and maintenance technicians work with their colleagues from the same shift and the next one as well as with personnel from planning, stores, etc. as part of a larger team to ensure that the task gets completed (FAA, 1991,1993; Gramopadhye and Kelkar, 1999). Thus, in a typical maintenance environment, the technician has to learn to be a team member, communicating and coordinating the activities with the other technicians and inspectors.

### **3. Responses to human factors issues in maintenance and inspection**

Over the last decade various federal human factors studies in maintenance-related issues have been initiated by agencies such as the FAA and NASA, by manufacturers, and by the aircraft maintenance industry. Examples of these initiatives are the National Aging Aircraft Research Plan (NAARP), the “Safer Skies” initiative, the White House Panel on Aviation Safety, and NASA’s aircraft maintenance program. The objective of all these has been to identify research issues and to promote and conduct both basic and applied research related to human factors in aircraft main-

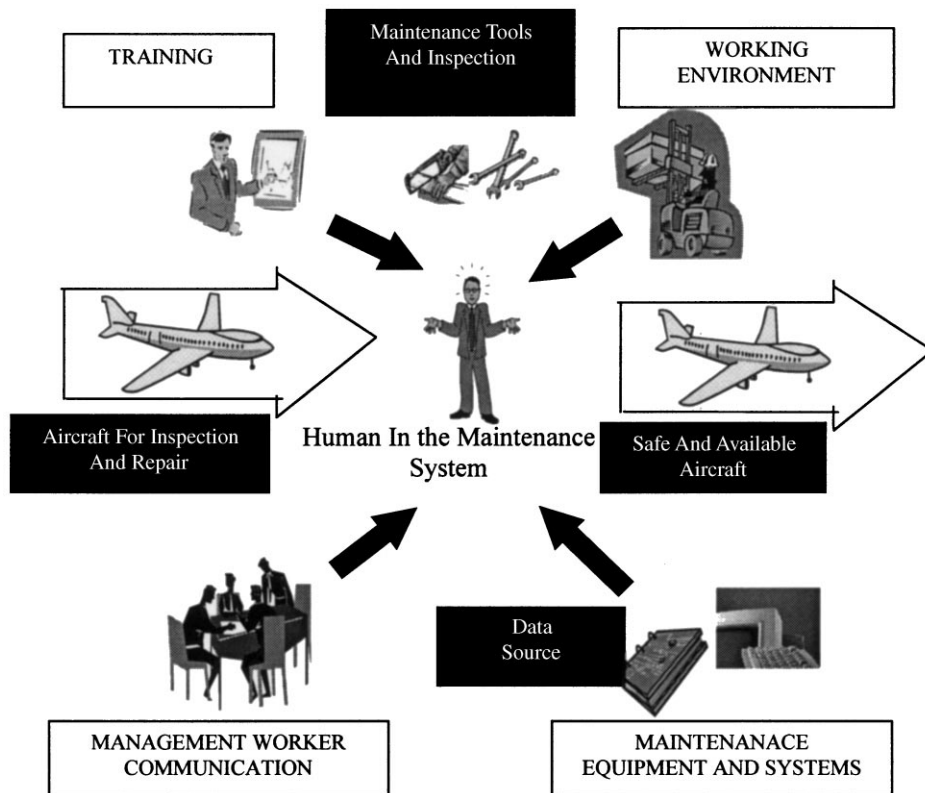


Fig. 3. Human in the maintenance system.

tenance. The human factors approach in maintenance research considers the human as the center of the system as Fig. 3 indicates. The inputs to the system are aircraft, shown to the left of the human. System outputs are safe aircraft. Not only can human factors research have a significant effect on the design of new systems but it can also mitigate problems found in the sub-optimal designs of current systems.

Human factors research brings a multi-disciplinary focus to human capabilities and limitations. For example, knowledge of psychology and physiology can help determine how much a human can remember or how much one can lift. The field of education can provide information on the ideal instructional methods and the length of time needed to ensure proper training. A systems engineering approach, a classic trait of human factors, ensures that all aspects of a task, job, or environ-

ment are sufficiently defined before alternative solutions are presented. The applied component of the research focuses on identifying human system mismatches to guide future research and short term/long term human factors implementation by researchers. Also, human factors research in the aircraft maintenance environment is intended to make human factor techniques more widely available to aircraft maintenance organizations and to make aircraft maintenance organizations more accessible to human factors researchers/practitioners. This research has been conducted by various participants including academic researchers, small and large corporations, and aviation maintenance consultants, a sampling of which has been provided as part of this special issue. The specific focus in selecting the articles found here was to provide the audience with a wide diversity in terms of both the content and the researchers.

In our sample of research we can see some underlying themes. First, there are the traditional human factors approaches to new problems, such as task analysis or error/ incident analysis. These provide a mapping of where human factors interventions may be effective in reducing error rates in the industry. Thus, Latorella and Prabhu's paper, that of Endsley and Robertson, and the paper by Walters all use a task analytic framework to discover where the key human factors issues may lie. In contrast, Rankin, Hibit and Sargent's paper and that of Wenner and Drury focus on the process of incident investigation to achieve the same ends. Ultimately, analysis of both past incidents and analysis of current tasks should give the same information, but typically the former focuses on the few rare events while the latter looks for potential human/system mismatches. It has become clear throughout the human factors involvement with aviation maintenance and inspection that an actual incident or accident is far more salient to managers and AMTs than even cogent analyses of what could happen.

Our sample covers not just data collection/analysis methods but also the development of effective interventions. Thus, training personnel such as AMTs and managers in human factors is represented here with papers by Taylor, by Walter, by Chandler and by Endsley and Robertson. Better analytic tools are represented by the modeling work reported by Melloy et al. and the MEDA incident analysis system developed by Boeing, and given in the paper by Rankin, Hibit and Sargent. Classic human factors interventions in hardware and job aids are detailed in the papers by Drury, Patel and Prabhu, and by Hastings, Merriken and Johnson. Finally, measurement of outcomes is a concern of both the industry and the researchers, as exemplified by Taylor's second contribution, the Technical Operations Questionnaire.

#### 4. Where do we go next?

Most of the papers here were commissioned between 1996 and 1997, representing the state of the research at that time. But progress continues. The FAA's Office of Aviation Medicine has held a series of annual meetings since 1989, initially to showcase

its research but more recently to demonstrate how the industry and consultants have responded to the challenge, producing their own interventions and advances. Most airlines, and even some third-party repair stations, now have active human factors programs. These programs train maintenance and inspection personnel, analyze incidents, change equipment, and apply information technology solutions to many of the operational issues we raise here. We now have a growing consultant base, largely focused on training, particularly on maintenance resource management (MRM) and based initially on successful programs involving aircrew, such as crew resource Management (CRM). A good current view of what is available can be found on the World-Wide-Web site maintained by the FAA for its program:

<http://www.hfskyway.com/>

For the future, there will be many more areas to research. We have seen the development of better job aids for training and task performance in such areas as inspection simulators and document design guides. A Handbook of Aviation Maintenance Human Factors has been published and widely disseminated in both hard copy and electronic form. In addition, Airline Maintenance Resource Management, a recent book on the training side of interventions, has been written by Taylor (1998). Military and space hardware must be maintained, leading to many of the same problems encountered in civil aviation, so organizations such as the US Navy and NASA are heavily involved. Applications of human factors techniques to improve reliability in aircraft inspection are on-going in a variety of contexts from laboratory-based research to field evaluations of inspection effectiveness. There are conferences at regular intervals, sponsored by the FAA, the Air Transport Association, and the Society of Automotive Engineers in the USA, and by bodies such as Transport Canada, and the European JAA. In addition, there are purely commercial conferences and exhibitions aimed at the wider use of human factors solutions in civil aviation.

Much has been accomplished since the wake-up call of the Aloha incident in 1988. We now have a relatively mature program where the fruits of the initial efforts of airlines, regulatory bodies and researchers are coming into general use. Aviation

maintenance and inspection has become a successful application area for human factors.

## Acknowledgements

We wish to express our gratitude to all authors and reviewers who took the time to report and review the papers. Professor Anil Mital is appreciated for providing valuable advice throughout the review and publication process.

## References

- Air Transport Association, 1994. The Annual Report of the US Scheduled Airline Industry [Brochure]. Washington, DC.
- Drury, C.G., Prabhu, P., Gramopadhye, A.K., 1990. Task analysis of aircraft inspection activities: methods and findings. Proceedings of the Human Factors Society 34th Annual Meeting, pp. 1181–1184.
- FAA, 1991. Human factors in aviation maintenance – phase one progress report, DOT/FAA/AM-91/16. Office of Aviation Medicine, Washington, DC.
- FAA, 1993. Human factors in aviation maintenance – phase three, Vol. 1. Progress Report, DOT/FAA /AM-93/15.
- Gramopadhye, A.K., Kelkar, K.P., 1999. Analysis of shift change in the aircraft maintenance environment: findings and recommendations. Technical Report. Office of Aviation Medicine, Federal Aviation Administration, 1999.
- Phillips, E.H., 1994. Focus on accident prevention key to future airline safety. *Aviation Week and Space Technology*, 52–53.
- Shepherd, W.T., Layton, C.F., Gramopadhye, A.K., 1995. Human factors in aviation maintenance: current FAA research. Proceedings of the Eighth International Symposium on Aviation Psychology, pp. 466–468.
- Shepherd, W.T., Kraus, D., 1997. Human factors training in the aircraft maintenance environment. Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting, pp. 1152–1153.
- Taylor, J.C., 1998. *Airline Maintenance Resource Management*. SAE International.
- Taylor, J.E., 1990. Organizational context for aircraft maintenance and inspection. Proceedings of the Human Factors Society 34th Annual Meeting, 1990.

Anand K. Gramopadhye

*Department of Industrial Engineering, Clemson University, Clemson, SC 29634, USA*

*E-mail address: agramop@ces.clemson.edu*

and

Colin G. Drury

*Department of Industrial Engineering,  
School of Engineering and Applied Sciences,  
State University of New York at Buffalo, 342  
Lawrence D. Bell Hall, P.O., Box 606050,  
Amherst, NY 14260, USA*

*E-mail address: drury@acsu.buffalo.edu*